Technical Bulletin
August 2003
DU #1

Subject: Duramax Engine – The Basics

Application: G.M. Duramax 6.6 L Diesel Engine

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The following Information is brought to you by the Technical Education Committee of the Association of Diesel Specialists
Supplement to Nozzle Chatter Winter Edition Volume 45, Issue 5

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EXPLORING THE DURAMAX

Understanding Chevy's New Electronic Diesel

Diesel engines all fire their mix using high compression, and they need precisely controlled fuel delivery, both in regard to timing and volume. Diesels typically spin slower than gas-burners, but the torque that diesel engines are capable of producing is practically legendary. That's one reason heavy-duty truck manufacturers went diesel on their heaviest platforms so many years ago. So, why does a diesel produce more torque?

The firing events on a given four-cycle cylinder are 720 degrees apart, and 720 divided by 8 is 90. Thus, a properly tuned V8 has a firing event every 90 degrees. However, because all the fire has gone out in each cylinder by the time the crankshaft is 25 degrees into the power stroke for the firing piston, the cylinders on a gas-burning engine are only briefly slapping the crankshaft every 90 degrees. The reason a diesel has so much more torque is that the fire starts later and diesel fuel burns slower; subsequently, the mix is burning and expanding all the way through the power stroke.

A diesel engine has an unrestricted flow of air, and the amount of carbon monoxide produced by a diesel engine is negligible. Diesel engines do, however, produce substantial amounts of NOX, as well as some hydrocarbons and particulate matter. For 21st century diesel light trucks to operate within legal emissions limits, many have been fitted with catalysts and EGR systems. These new emissions-friendly diesels, like their older counterparts, depend very heavily on the precision with which the injection of fuel is controlled. Cummins diesel engines, depending on the platform, utilize either high fuel pressure of 17,000 psi and mechanically driven "top stop" injectors or pump-driven nozzles that pop at about 4,500 psi when provided with carefully timed bursts of fuel pressure from an electronically manipulated Bosch "smart pump."

For those unfamiliar with Ford's Power Stroke diesel engine, it should be noted that it uses from 500 to 3,000 psi of electronically controlled lube oil pressure applied to the top of a 7-to-1 intensifier piston built into the injector itself. Because the 500 to 3,000 psi of control oil pressure is multiplied by seven, the fuel injection spray pressure runs from 3,500 to 21,000 psi.

The Duramax diesel fuel system needs the same super pressures that all diesels need in order to properly inject the fuel. However, instead of using bursts of high fuel pressure or lube oil pressure, the Isuzu/Bosch team decided to jack the fuel pressure up continuously with a special pump and control the injection with a special module, high voltage and electronic injectors.

Duramax fuel delivery
Ford's first-generation Power Stroke fuel pump used a two-stage fuel pump to bring the fuel from the tank to the engine and then pressurize it around 50 psi for delivery to the injectors. In comparison, the Duramax also uses a two-stage fuel pump, but rather than utilizing a diaphragm-type pump for lift, a pair of spur gears is used to bring fuel from the supply. The spur gear pump creates about 5 inches of vacuum to draw fuel from the tank, where it first passes under the Fuel Injector Control Module (FICM). The FICM is a neatly boxed array of step-up transformers and electronics similar to the Power Stroke's

Injector Driver Module.
The reason the fuel passes under the FICM is to keep the module cool. Then it is drawn through a heater-equipped filter/separator, which has a priming pump and a bleed screw, before reaching the two-stage fuel pump. The spur gears feed the fuel into the high-pressure side of the pump, which is a radial design with three pistons set 120 degrees apart. This camshaft-driven pump only consumes a fraction of the torque necessary to drive a normal injector pump and is capable of producing nearly 30,000 psi of fuel pressure. The pump pressure obviously must be regulated,

and for safety purposes, the Bosch folks designed a pop-off valve that feeds excess pressure back into the return side of the system.

The fuel pressure is electronically controlled by the Fuel Rail Pressure Regulator (FRPR). The FRPR is a duty-cycle solenoid mounted in the pump and controlled by the Electronic Control Module (ECM) based on feedback from a sensor in the junction block that provides fuel to the supply rails. The FRPR duty-cycle operates in a 5 to 95 percent window, and unplugging the solenoid drives the fuel pressure to the maximum level instead of vice versa, as we might expect. The ECM increases pulse width to lower pressure, so if the solenoid receives a 100 percent duty-cycle for some reason, pressure will be at its lowest, and performance will obviously degrade. A 5 percent duty-cycle will produce a fuel pressure of 23,200 psi, and a 95 percent duty-cycle feed will produce a 5,000 psi reading. The pressure should never go below 3,000 psi; if it does, something is wrong. The Tech 2 scan tool provides target and actual fuel pressure readings for diagnostic purposes.

A frame-mounted electric fuel pump is used on units with dual tanks, but it doesn't directly provide fuel to the engine. It only transfers fuel from the auxiliary tank to the primary tank when the fuel level gets below a certain level. The ECM controls the relay that drives the pump and monitors the fuel level to determine when the pump should be energized.

On the Power Stroke, the Injection Control Pressure regulator, which is similar but opposite in function to GM/Isuzu's FRPR, operates on a duty-cycle from zero to 65 percent, and oil control pressure drops to zero with the regulator unplugged. If the ICP control wire shorts to ground, the pressure goes as high as 3,750 psi, relieved by a pop-off valve in the high-pressure oil pump. Use common sense safety practices when servicing any diesel system: While maximum control oil pressure on a Power Stroke can reach nearly 4,000 psi, the Duramax fuel system is pressure-relieved at a blistering 27,550 psi. Cracking a fuel line loose on a running Duramax engine could easily be fatal. Don't go there. And don't fool with the Duramax fuel rail bleeder valve unless the engine is at rest and the pressure has been relieved.

The junction block
Fuel is fed from the high-pressure pump to a junction block that sends fuel to the "common rails," which provide controlled fuel pressure to the injectors. The Fuel Rail Pressure (FRP) sensor is mounted in this junction block, along with the mechanically operated pressure relief valve. The sensor is a three-wire design that receives the familiar 5 volts and provides a signal return. If fuel pressure exceeds 27,550 psi, the relief valve unseats and bounces to maintain fuel pressure at that level. Relief pressure is vented into the return system through a line attached to the junction block. Remember, maximum controlled pressure is 23,200 psi, and anything above that should be compared to the scan tool reading of the FRPR pulse width the ECM is providing for detailed analysis.

If the FRP sensor is removed from the junction block for any reason, GM procedures call for replacing the sensor with a new one. The soft iron seat will be deformed the first time the new sensor is torqued, and the old sensor might not seal properly if reused.

Common rails and injectors
The common rails are similar to the oil rails on a Power Stroke, but they carry fuel instead of oil, and they're mounted externally instead of under the valve cover or cast into the cylinder head. The volume of each common fuel rail is 16 cubic centimeters and they serve as reservoirs to provide a constant volume of fuel and to dampen oscillations as the injectors operate. Short metal lines carry the fuel from the rail to each injector, and metal return lines return the fuel through a small radiator-like cooler. The return fuel must be free-flowing all the way back to the supply.

The Bosch injectors are directly in the center of the four-valve combustion chamber; this is a direct injection system with no precombustion chambers. The ECM is programmed to operate the injectors in two stages; an early, small shot of fuel starts the fire in the combustion chamber and is immediately followed by a larger amount of fuel. This strategy reduces noise and hydrocarbon emissions.

The 7.3L Power Stroke engines have used basically the same split-shot injector strategy for years, but the primary difference is that the 7.3L Power Stroke nozzles had the split-shot design mechanically built into the injector itself. The new 6.0L Power Stroke handles split shot injection more like the Duramax, but it uses two solenoids and a special electronic strategy to provide the double injection for each injector cycle and still operates with high oil pressure.

Diesel electronics, GM style

Quite obviously, the heart of the Duramax electronic diesel is a Delphi 32U ECM, and it has been nestled in the same familiar corner of the engine compartment in GM trucks for a few years now. The ECM communicates with the Fuel Injector Control Module (FICM) on a 250,000 Baud rate J1939 CAN bus network (the new 6.0L Power Stroke also uses a CAN bus between its PCM and Injector Control Module). However, data exchanges with the scan tool Diagnostic Communication Link (DLC) are handled with Class 2 data protocol. Fuel injection quantity and timing are calculated in the ECM and sent to the FICM, where the step-up transformers juice normal system voltage up to a crisp 93 volts to operate the injectors sequentially with high-speed switching drivers. The Duramax cylinder numbering may confuse older Chevy lovers: They're numbered exactly like the Power Stroke, with odd cylinders one through seven on the passenger-side bank and even cylinders two through eight on the driver's-side bank. The firing order is 1-2-7-8-4-5-6-3 – not that you're likely to get anything crossed up. (Just for grins, the Power Stroke firing order is 1-2-7-3-4-5-6-8.)

Incidentally, the Tech 2 doesn't talk directly to the FICM, but injector trouble codes are generated by the FICM and sent to the ECM when problems occur on that side of the system. GM says not to attempt harness repairs on the high-voltage side of the system, but to replace the harness if anything goes sour on the 93-volt circuits. Wiring repairs on the low-voltage side of the FICM and the rest of the ECM spider web can be handled in the normal manner.

Looking for concerns

My technician contact at the local high volume Chevy dealer reports very few problems with Duramax engines, and the problems that do occur don't seem to repeat themselves. He mentioned one squeaky rocker arm and blown head gaskets on two different high-mileage vehicles, but no recurring problems.

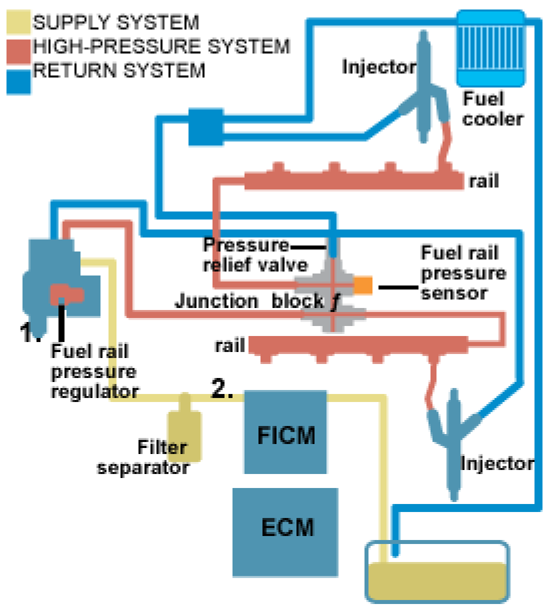
As for troubleshooting the Duramax, it's best to use a strategy that won't lead down rabbit trails. Verifying the concern is a good idea. Checking the air filter minder is another good practice. Also, check for unseated connectors, but be careful not to disturb things too much if you're looking for an intermittent. Don't risk probing the high-voltage wires leading to the injectors: Adhere to shop manual procedures for checking the 93-volt circuits. An electrically triggered heart attack could ruin your whole day. And once again, don't open the fuel system until you're sure the pressure is at safe levels.

Yank the dipstick and look for low or nasty oil or overfull conditions that may indicate fuel contamination of the crankcase oil, among other things. Number 2 diesel usually has a specific gravity of 30 to 39 and Number 1 diesel gravity is from 39 to 44. GM's tool number for measuring this is J 38641 B. Make sure the appropriate fuel is being used: Off-road diesel – dyed red or blue – is a no-no.

Check for restrictions or air leaks in the fuel supply line for hard-starting/low-power problems. Zero to 5 inches of mercury supply line vacuum is normal on a running engine. Measurements between 5 and 10 inches indicate the need for a filter change. After 15 inches, performance will degrade dramatically, and more than 20 inches of measured vacuum is enough to starve the engine into a no-start condition. For investigating air leaks in the supply line, a clear hose installed between the FICM outlet and the filter inlet works well.

White smoke generally indicates intake heater or glow plug concerns. Black smoke comes from air leaks in the intake system downstream of the MAF sensor. Noisy or knocking combustion may indicate a leaking injector. Hunting idle concerns may indicate fuel pressure control problems.

Plug in the scan tool and pay attention to DTCs, fuel pressure and temperature, target or desired readings versus actual values. Familiarizing yourself with normal scan tool readings on as many good vehicles as possible is a powerful tool for recognizing faults on any problem vehicle.



1. High-pressure pump is driven by the camshaft, but no timing marks are necessary.

2. Supply fuel runs under the fuel injection control module (FICM) to keep it cool.

Sensors

Crank (CKP) sensor
A Hall-effect sensor used to calculate rpm and crankshaft position, as well as to monitor misfires during the first 90 seconds of engine startup. There is a 60-minus-three tooth trigger wheel mounted on the front of the crank gear, leaving 57 teeth and a three-tooth gap to provide a break in the magnetic flux. This is a critical signal used by the ECM and FICM to operate the injectors. Interestingly, the new 6.0L Power Stroke crank sensor uses a 60-minus-two tooth wheel.

Cam (CMP) sensor
A Hall-effect sensor used in conjunction with the CKP sensor to determine which cylinders are at TDC compression, thus calculating injector firing order. The CMP generates three pulses per two crank revolutions and is only used for injector initialization on startup.

Fuel Rail Pressure
(FRP) sensor
A pressure-sensitive transducer mounted in the fuel distribution junction box. It receives a 5-volt reference feed and contains a tiny internal printed circuit and some electronic evaluation hardware that processes and amplifies the pressure sensor signal before it is sent back to the PCM. Range of output voltage is from 0.5 to 4.5 volts. According to GM, the FRP sensor should always be replaced if it is removed from the junction box for any reason. If the sensor fails, the ECM defaults to “Limp-In” mode, derating the engine and limiting engine speed to 2,000 rpm.

Fuel Rail Temperature (FRT) sensor
Mounted under the turbocharged air outlet duct, the FRT sensor is a two-wire Negative Temperature Coefficient thermistor that the ECM uses to monitor fuel temperature. Because the fuel passes through a small radiator-style cooler (mounted underneath the cab), check for clogged cooler fins if the fuel temperature climbs too high.

Engine Coolant Temp (ECT) sensor
Operates in two stages using a step-up circuit in the ECM. From -40°C to 50°C, the voltage drops steadily from just under 5 volts to 0.96 volts. At 50°C, a current switch takes place in the ECM. The ECT voltage jumps back up to just above 3.5 volts, thereafter decreasing at about the same rate. It usually stabilizes at around 1 to 2 volts with the engine at normal operating temperature. This stepped ECT strategy has been used by GM and Chrysler for several years now.

Intake Air Temp sensor
Built into the MAF sensor, it provides temperature of incoming air. Operation is similar to the ECT sensor.

Mass Airflow
(MAF) sensor
The MAF provides the ECM with information on incoming air mass and density. Debris on the MAF sensor will obviously degrade engine performance.

Vehicle Speed
sensor (VSS)
The VSS contains a magnet that rotates inside a winding and produces an AC current that increases in amplitude and frequency with vehicle speed. The AC signal is converted to a digital signal by the VSS buffer circuit in the ECM.

Boost sensor
The boost sensor measures intake manifold pressure, a critical input for the ECM on a turbocharged engine. The ECM considers Boost Sensor information for load-sensing purposes to assist in fuel and timing requirements. Also, a BARO sensor is mounted on the left valve cover for altitude modification to fuel strategy.

Accelerator Pedal
Position (APP) sensor
The Duramax is a drive-by-wire application, and for safety pur-poses, this sensor has three redundant circuits feeding APP to the ECM. Each of the three accelerator pedal sensors has its own 5-volt VREF (Reference Voltage) feed and signal return. APP 1 voltage ranges from about 0.75 volts at closed throttle to as high as 4.29 volts at WOT.

APP 2 starts at 4.29 volts at closed throttle and outputs 2.98 volts at WOT.

APP 3 ranges from 3.98 volts at closed throttle to 3.2 volts at WOT.

If one of the three APP sensors fails, the ECM will store a code, but engine operation will be normal. If two APP sensors fail, engine performance will be degraded by the ECM and DTCs will be stored. If all three APP sensors fail, the engine will operate at idle only. In comparison, Ford's Power Stroke uses one APP sensor and an Idle Validation Switch

ACTUATORS

Intake Air Heater
To prevent white smoke on start-up from cool incoming air, the ECM will energize the Intake Air Heater for 180 seconds as needed.
On the Power Stroke, the intake air heater is activated only once during a key cycle and may function only at low idle when ambient air and engine oil temperatures are low and the glow plugs are off.

Glow Plugs
If coolant and air temperature readings justify glow plug operation, the ECM energizes the glow plug relay, which provides current to the glow plugs through a bus bar, before engine starting and for 30 seconds after the engine is running. California trucks are required to monitor glow plug operation through feedback circuitry and are wired differently. The glow plugs are below each valve cover.

Injectors
Each individual injector is controlled by the ECM via a 93-volt DC signal from the Fuel Injector Control Module (FICM). Moving the injector bleed orifice ball off its seat requires 18 amps, but once the injector is open, 12 amps will hold the ball up until injection is complete. The high and low side injector drivers are monitored by the FICM for errors, and the information is sent via the CAN bus network to the ECM where they're stored for scan tool retrieval. The ECM sends a separate signal to the FICM to operate each injector, and the ECM-to-FICM circuits are monitored for problems as well.

Fuel Rail Pressure
(FRP) Regulator
Mounted on the high-pressure pump, this 12-volt, spring-loaded regulator is normally open and is controlled by the ECM. The duty-cycle range runs from 5 to 95 percent. If the FRP sensor indicates higher pressure than the ECM target for a particular load/demand, the low side driver duty-cycle will increase to lower the pressure. Low pressure will result in the ECM reducing the duty-cycle. Unplugging the sensor will drive the fuel pressure to its high limit. A
shorted control circuit will result in low pressure and a no-start. Both the 12-volt feed and the control circuits come directly from the ECM.

EGR system
The EGR valve is a old-style vacuum-operated unit. It is operated by two ECM-controlled vacuum solenoids using vacuum provided by a belt-driven pump and an EGR throttle valve to generate a mild intake restriction, so the exhaust gas flowing through the EGR valve will flow into the intake. The new 6.0L Power Stroke uses an electrically operated throttle valve for this same purpose